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Research paper

A Study on Design of Microgrid(MG) Optimal Operation Algorithm for Development of Semi-Wheel System

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Abstract

Background/Objectives: Recently, due to the change of power paradigm, interest in MG(Microgrid) is increasing. However, the realization of MG requires very sophisticated algorithms. Therefore, before implementation, we want to develop a virtual MG operation system that can verify economical & efficient feasibility.
Methods/Statistical analysis: In this paper, we design MG optimal operation algorithm as the first step for the development of Semi-Wheel-System. The design method is to analyze the MG components in the Geocha island. Especially, the fuel consumption per diesel generator output and characteristics of BESS battery are analyzed. Matlab, SPSS is used to apply the curve fitting technique and trend prediction.
Findings: As a result of designing the optimal operation algorithm that MG can operate most efficiently, the diesel generator is controlled to the optimum power ratio of 60 ~ 80%. And the BESS SOC range is controlled by setting the average value of 42.5%by using the analysis result. The simulation scenarios are designed based on the comparison of renewable energy power supply and power demand. Also, the application of the diesel generator efficiency and BESS SOC setting characteristics are also reflected. Thus, a total of 12 scenarios are constructed. As a result of simulation, it is verified that the fuel consumption of the diesel generator is minimized and the maximum energy of the BESS is obtained after the algorithm proposed in this paper is applied on it.
Improvements/Applications: In future research, we will construct a virtual MG operation system, which can reflect various grid situations, characteristics of MG elements, and control and measure variables.

Keywords: *semi-wheel system, microgrid, pre-validation, BESS, diesel Generator, virtual analysis*

1. Introduction

Due to the changes in the power industry paradigm, the global power industry is concentrating on designing a way to go to the distributed power grid. In particular, the Paris Climate Change Agreement in 2015 marked the beginning of the government's active move toward greenhouse gas reduction, and interest in distributed power sources has surged[1]. MG(Microgrid) is at the center of these changes. The MG is classified into a grid-connected type connected to the existing KEPCO grid and a stand-alone type that receives power only from its own distributed power source. In case of grid-connected MG, modeling is very difficult, complicated and expensive because it is directly connected to KEPCO grid. Also, In the case of stand-alone MG, It is essential to research the characteristics of construction. And detailed grid operation strategy must be designed. In addition, since the MG is composed of a system based on a renewable energy source, the power supply may be unstable due to its depending on the natural environment. In order to solve this problem, the use of BESS should also be considered, and analysis of various other components is required. If these various considerations can be verified before actual implementation, MG stability, economy, efficiency will be secured. This paper is the first step to proposed the Semi-Wheel System, a virtual operating system that can simulate power conversion, remote measurement and control of MG[1,2].

In this paper, we use the data of Geocha island where the stand-alone MG is constructed, analyze the characteristics of MG components in Geocha island, and design the optimal operation algorithm to operate it efficiently. The validity is verified through simulation. This analysis is meaningful as a precedent research for the development of the Semi-Wheel System, a virtual MG simulation operating system.

2. Case Study and MG components analysis

Geocha island is located in the southernmost island of Korea and is divided into West island and East island. There are about 300 inhabitants of the island. In the past, Geocha island is 100% self sufficient in power using three 150kW diesel generators in the West island. However, recently, a stand-alone MG had been established as a target area for the government's energy independent island project. As a result, a 150kW diesel generator is added for emergency power generation. And total of 120kW PV power plant, a 100kW wind turbine, and a 500kWh 500kWh BESS and 250kVA inverter system for energy operation stabilization were constructed.

The microgrid of Geocha island is composed as shown in Figure 1. It is a stand-alone MG that is not supplied with KEPCO power.

It is largely classified into Energy Supply Section, Energy Demand Section, and Energy Storage Section. The Energy Supply Section include diesel generators, PV power generators, a wind power generator. The Energy Demand Section consists of linear load, nonlinear load, and Energy Storage Section consists of BESS.

2.1. Load, Wind, Pv

As shown in Figure 2, the Geocha island shows a different load pattern from that of a typical urban area. Due to the fishery environment of Geocha island, the amount of electricity used in January and February is very low and the electricity consumption at night is very high in March. Also, electricity usage in the morning hours is high at early morning. The annual load of the Geocha island is 124kW, the maximum load is 305kW, and the minimum load is 80kW. The renewable energy sources constructed on Geocha island are solar and wind power generation. But, the ratio of renewable energy source to load is as low as 21.76%. It is difficult to find out if the amount of renewable energy generated exceeds the load even if the actual operation data for one year is checked, and it is insufficient to cover industrial and fishery loads with renewable energy generation power. In addition, PV power can only be supply power during the time when the sunlight appears, and wind power can only be supplied when the wind is blowing. However, since there is a time gap between the supply of renewable energy and the use of the load for the Geocha island, it is necessary to use BESS that can store renewable energy generation power and supply it at a time when power demand is high, and use of existing diesel generator is inevitable.

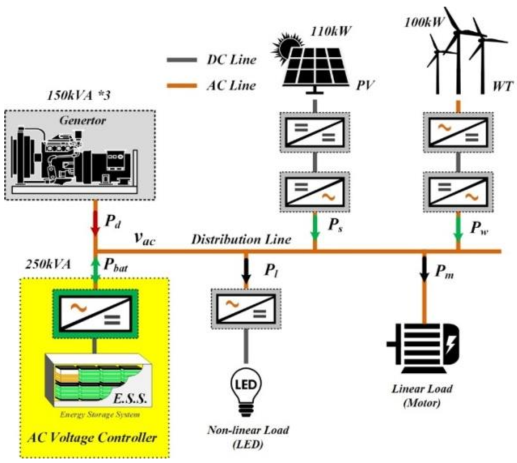


Figure 1: Configuration of Geocha island MG

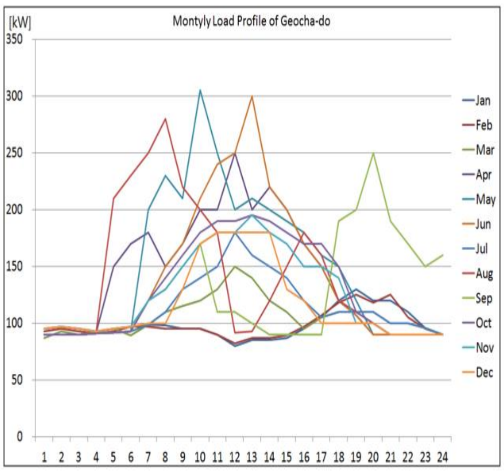


Figure 2: Monthly Load Pattern of Geocha island

2.2. Diesel Generator

There are four diesel generators in Geocha island, three of which are already in operation and one that has been newly installed for emergency power generation. Because Geocha island has a low rate of renewable energy generation compared to electricity demand, there is a need to operate the diesel generator at all times to ensure stable production activities. In fact, considering the eco-friendliness purpose of the government's energy independent island project, it is reasonable to add renewable energy sources. However, in the end of the project, the economic burden of inhabitants is inevitable to construct additional renewable energy sources. Therefore, in this paper, we have devised a strategy to operate diesel generators which must be operated inevitably more efficiently.

Analysis of the fuel consumption of the diesel generator shows that between 50% and 100% of the output, fuel consumption per output, which is closely related to power generation efficiency, appears almost similar. But falls sharply below 50%[3,4]. That is, generally, the diesel generator has a characteristic of lowering efficiency when driven at low output. Therefore, it is helpful to improve diesel generator efficiency by keeping the proper output ratio [3]. The fuel consumption based on the output power ratio of the 150kW diesel generator is the same as the black spot in Figure 3.Calculating the fuel consumption per 1 kW output, the fuel consumption per output is about 0.26L/kWh at 60% and 80% of the output. As the output ratio decreases, the fuel consumption per output is shown to be 0.3L / kWh at 20%, and 0.27L / kWh at 100%, which will rise to about 15% depending on operating conditions. The solid line in Figure 3 is obtained by using the curve fitting technique to obtain the continuous data value based on the fuel consumption test results. The derived function is shown in Equation (1).The graph also shows that the range with the lowest fuel consumption is when the output ratio is 60 ~ 80%.

$$c = 1.32346 - 1.04408r + 1.00092r^2 - 0.24957r^3 \quad (1)$$

Where c is a function derived from the curve fitting technique, r is the output ratio to the diesel generator rated output.

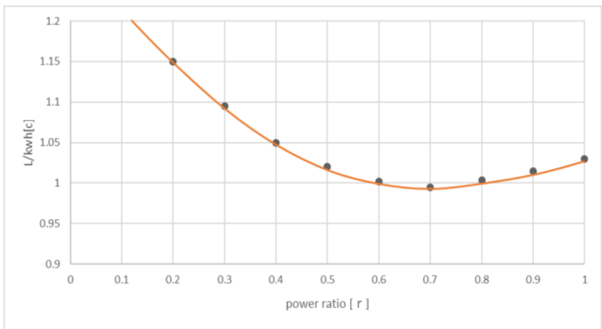


Figure 3: (150kW) Fuel Consumption ratio per Diesel Generator Output Power (curve fitting)

2.3. Bess

Renewable energy has a problem that power supply is unstable due to characteristics that depend on natural conditions. This is a factor that can make the reliability of grid lower, and it is common to build an BESS that can store renewable energy generation and supply it when needed[5]. Geocha island has low use BESS because of low renewable power generation. But, there are many cases where loads are used at times when it is difficult to supply renewable power as shown in Figure 2. So, BESS may be needed for stable power supply. In addition, depending on the diesel generator algorithm, the diesel generator may be further operated to store power in the BESS.

The BESS built on Geocha island is equipped with a Li-ion battery and the algorithm is designed to reflect the characteristics of the DOD and SOC of the Li-ion battery[6,7,8,9]. The DOD(Depth of Discharge), which is the charge/discharge characteristic of the battery, indicates the degree of discharge in the total capacity of the BESS, and the opposite concept is the SOC(State of Charge), which is often called the remaining capacity[10,11]. Generally, the battery life on the DOD setting. The higher the DOD(that is, the closer to the full discharge), the shorter battery life. The lower the DOD, the longer battery life. Also, when the available capacity is reduced to 70% of the new battery capacity, the battery is determined to be aged and replaced[12]. As shown in Figure 4, the ratio of total energy obtain up to the replacement period of the SOC standard is derived by reflecting the DOD characteristics. When SOC is set to 35~55%, it can be confirmed that the largest energy can be obtained.

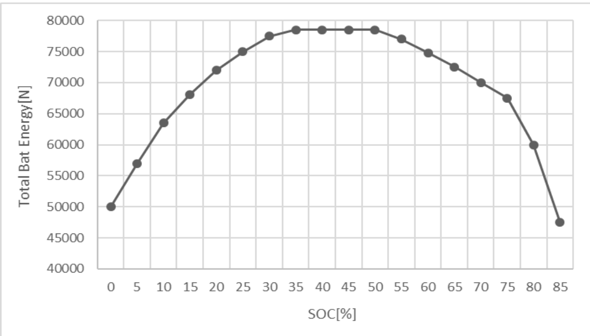


Figure 4: Total Energy Obtain Ratio until Replacement Time of Li-ion Battery

3. Proposed Optimal Operation Algorithm of MG

Renewable energy is determined by the natural environment, and the linear load and the nonlinear load are determined by the usage environment of the customer. Therefore, renewable energy and load are classified as uncontrollable disturbances in MG operation algorithm design. This can be expressed in Equation (2), Equation (3).

$$P_{dis} = (P_l + P_m) - (P_s + P_w) \quad (2)$$

$$P_{bat} = P_d - P_{dis} \quad (3)$$

Where P_{dis} is disturbancespower, P_l islinear load, P_m is non-linear load, P_s is PV power, P_w is wind power, P_{bat} is absorbed power of inverter, P_d isdiesel generator power.

Equation (2) is the disturbance power(P_{dis}) obtained by subtracting the renewable energy factor, which is the combined PV power(P_s) and wind power(P_w), from the disturbance factor of the linear load(P_l) and the non-linear load(P_m). Equation (3) represents the power to be absorbed in the inverter for BESS(P_{bat}) by subtracting the disturbance power(P_{dis}) from the diesel generator(P_d). That is, it is derived by subtracting the output of the diesel generator and the power obtained by subtracting the renewed energy from the load. Therefore, the inverters for BESS only control the grid voltage, and the BESS power is determined by other devices. If the disturbance is positive, the diesel generator is the only generator that can control the BESS power. In this case, to make the BESS charge & discharge current zero, the diesel generator power should be controlled with disturbance power. However, if the disturbance is negative, there is no power source to control the BESS power, so the BESS absorbs both the disturbance power and the generator power.Also, if the renewable generation power is greater than the load power, the diesel generator can not absorb the power, so the BESS must absorb at least the difference in power. Based on this, we designed the algorithm according to the characteristics of the diesel generator and BESS based on the analysis results of the chapter 2.

First, the analysis of the fuel consumption per output ratio of the diesel generator shows that the most efficient rated output range of the generator is about 60 ~ 80%. However, according to the existing research cases, the diesel generators decrease power generation efficiency according to the operating time, and generally reduce by 10% when operating 50,000 hours[13]. The diesel generators of Geocha island have been in operation for a very long time. Therefore, reflecting the results of the existing research and the opinions of the experts, based on the rating of 150kW of diesel generator, 90kW ~ 120kW, which is 60 ~ 80% of the maximum efficiency range, is set to 80kW ~ 120kW to reflect the efficiency reduction. In the case of BESS, the maximum energy obtain ratio is 35 ~ 55% in SOC, and the average of 42.5% in this scope is set as SOC standard. In other words, when operating the BESS, the SOC is adjusted to 42.5%, but the deviation error is kept at 35 ~ 55%. The operating algorithm of Geocha island MG is configured as shown in Figure 5. The operating number of each diesel generator is determined to be as close as possible between 80 kW and 120 kW, and when the output is less than 80 kW, the diesel generator is configured to close to the maximum efficiency scope by discharging the power of the BESS. In case of more than 120kW, the power is absorbed in the BESS so that the diesel generator approaches the maximum efficiency scope.

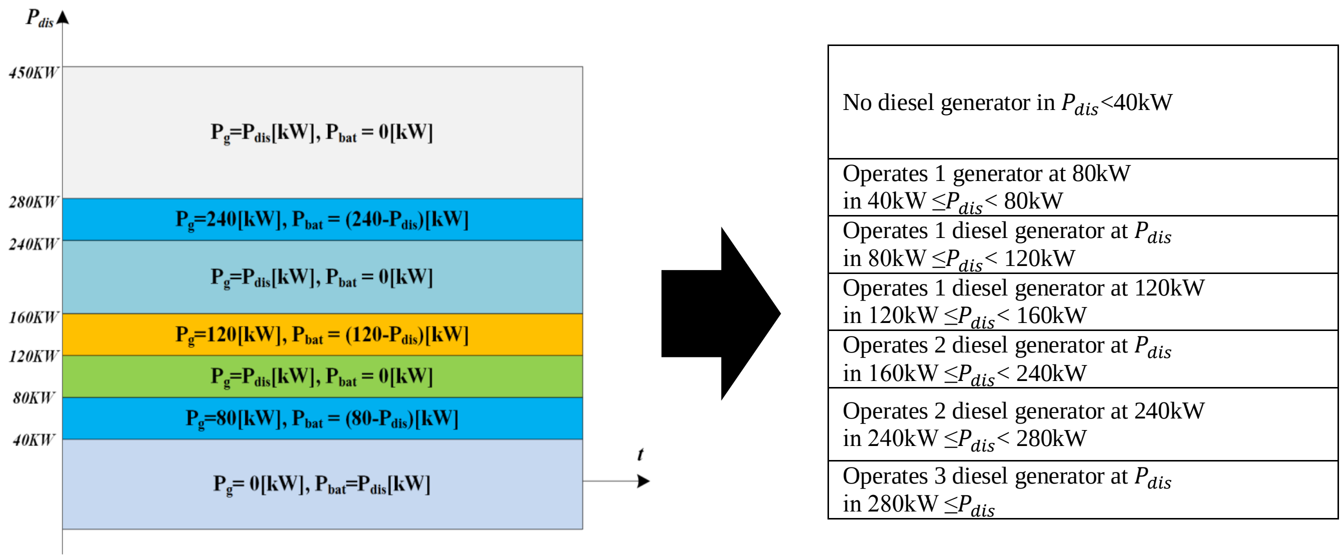


Figure 5: Design of Optimal Operation Algorithm for MG

4. Simulation

4.1. Scenario

In order to verify the optimal operation algorithm of BESS and diesel generator, simulation scenarios are designed as shown in Table 1. Variable 1 is the classification according to the grid situation. Scenario 1 uses data from January 1, 2016 when the load is larger than renewable energy generation. Scenario 2 uses data from October 5, 2016, when renewable energy generation and load are the same. It is difficult to find the ratio of renewable energy generation over load. Therefore, Scenario 3 is further designed by processing the data of October 5, 2017 used in Scenario 2 so that the renewable energy generation amount is larger than the load amount. Variable 2 reflects the efficiency of the diesel generator depending on the output ratio. Scenario A is not considered it and Scenario B is considered it. Variable 3 is whether or not the BESS's Li-ion battery characteristics are reflected. The diesel generator priority mode and the BESS priority mode are further classified because the diesel generator is not driven when the diesel efficiency is not taken into consideration.

Table 1: Simulation Scenarios

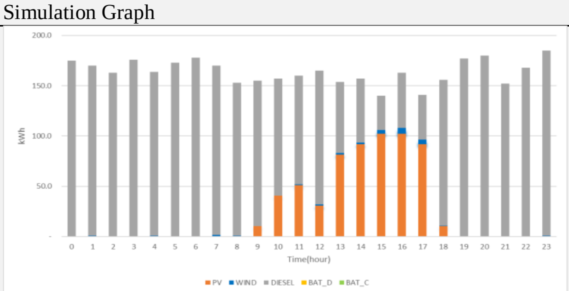
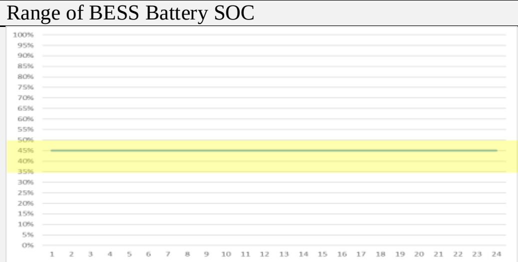
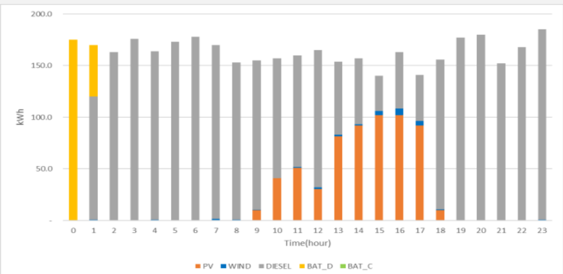
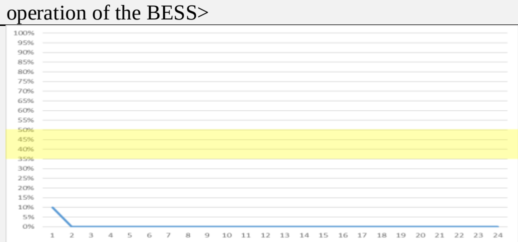
(Variable 1) Situation		(Variable 2) Diesel generator efficiency		(Variable 3) BESS Battery SOC Characteristic	
Scenario1	PV+WIND <LOAD (2016.01.01)	Scenario1-A	Not considered	Scenario1-A-a	Not considered(Diesel priority)
				Scenario1-A-b	Not considered(BESS priority)
		Scenario1-B	Consider	Scenario1-B-c	Not considered
				Scenario1-B-d	Considered
Scenario2	PV+WIND =LOAD (2016.10.05)	Scenario2-A	Not considered	Scenario2-A-a	Not considered(Diesel priority)
				Scenario2-A-b	Not considered(BESS priority)
		Scenario2-B	Consider	Scenario2-B-c	Not considered
				Scenario2-B-d	Considered
Scenario3	PV+WIND >LOAD (Edit Data : 2016.10.05)	Scenario3-A	Not considered	Scenario3-A-a	Not considered(Diesel priority)
				Scenario3-A-b	Not considered(BESS priority)
		Scenario3-B	Consider	Scenario3-B-c	Not considered
				Scenario3-B-d	Considered

4.2. Simulation Results

Based on the scenario constructed in Section 4.1, the actual data of Geocha island is used and the optimal operation algorithm proposed is applied. For all scenarios, the initial BESS charge is set at 225kWh for comparison between scenarios. The simulation results for each scenario are shown in Table 2, 3, and 4.The left graph shows the grid flow of the Geocha island with time, and the right graph shows the operating range of BESS SOC with time. When the SOC is in the yellow color range, the maximum energy can be obtained. Also, the graph color are composed of PV(Orange), Wind(Blue), Diesel(Gray), Battery_Discharge(Yellow), Battery_Charge(Green).

Table 2 shows the simulation results for Scenario 1. The actual data of January 1, 2016, when there is no time zone where the renewable energy generation power exceeds the load power. At that time, the amount of wind power generation was extremely small, the area of solar power generation time was narrow, and the pattern of power consumption at all times was uniformly consumed. The diesel power generation operation is determined by the load in 1-A. And 1-B reflect the efficiency of the diesel. 1-A-a is diesel priority mode that the diesel generator supplies power without considering efficiency. 1-A-b is BESS priority mode that BESS is operated first at the start of zero section. In 1-B-c, diesel generators operate only at the optimum efficiency level, and the rest is discharged from BESS in section 8, 9. Diesel generators output is exceeding the load, which is charged to the BESS in section 16, 17. As a result, it can be confirmed that the BESS SOC is controlled by 30 ~ 50% at 1-B-d using the proposed algorithm.

Table 2: Simulation Results :(Scenario 1) PV+WIND < LOAD

Scenario	Simulation Graph	Range of BESS Battery SOC
1-A-a		 <The initial charge of 42.5% is maintained due to the un-operation of the BESS>
1-A-b		 <Section 1, which is the starting point of the above graph, starts at 10%, which is the SOC after discharging the Section 0 of the left graph.>

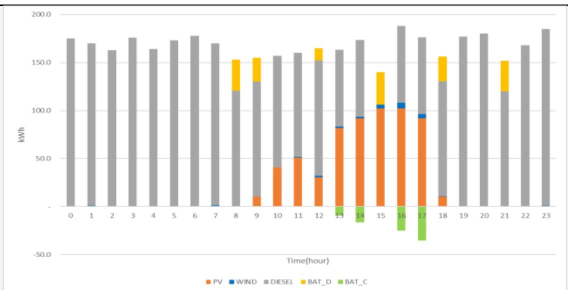
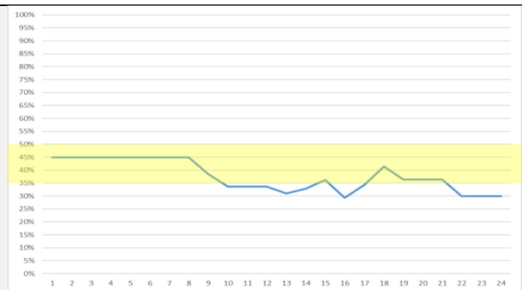
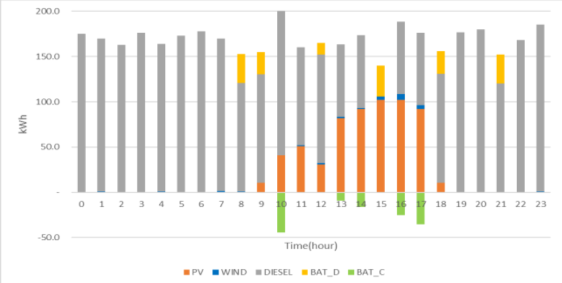
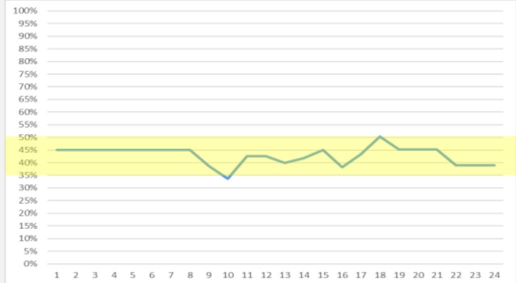
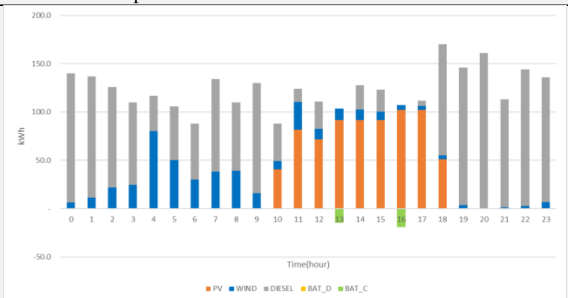
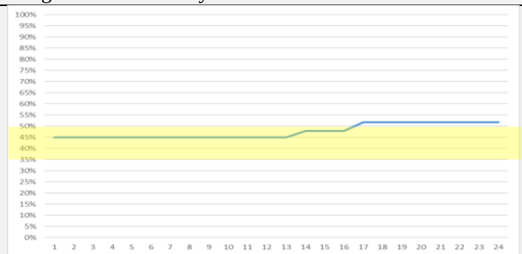
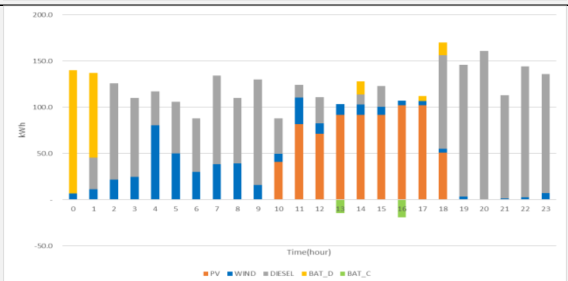
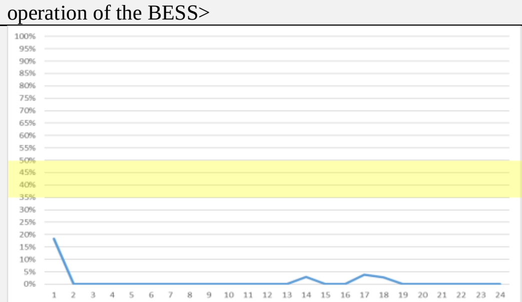
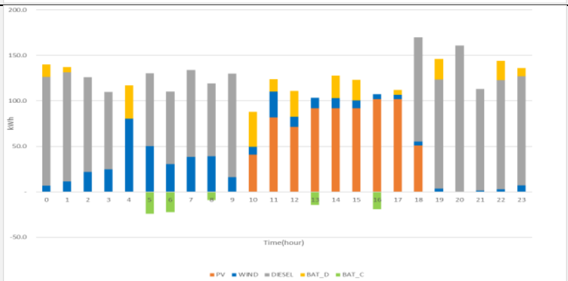
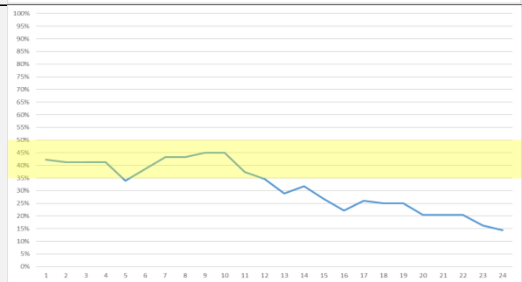
1-B-c		
1-B-d		

Table 3 shows the simulation results for scenario 2. And actual data of October 5, 2016, where the renewable energy generation power and the load power are in the same time zone, is used. At that time, At that time, the wind power generation was relatively abundant, and the area of solar power generation time was not wide. Unlike Scenario 1, the load pattern showed a high variation over time. The operation method is the same as the scenario 1. The unusual point is that it does not work under the load less than 40kW and discharges in BESS according to the proposed algorithm in 2-B-c. Also, in 2-B-d, there is a period in which the operation of the diesel generator is increased in order to maintain the optimal operation charge / discharge range of the BESS.

Table 3: Simulation Results: (Scenario 2) PV+WIND = LOAD

Scenario	Simulation Graph	Range of BESS Battery SOC
2-A-a		 <The initial charge of 42.5% is maintained due to the un-operation of the BESS>
2-A-b		
2-B-c		

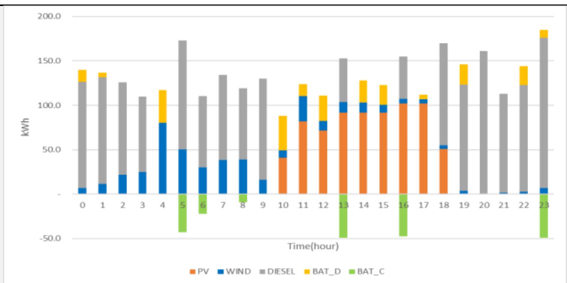
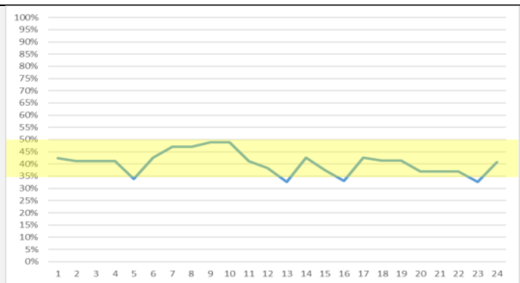
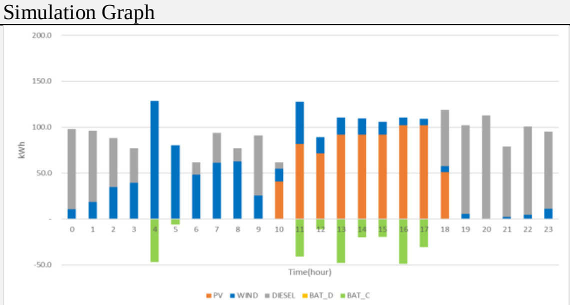
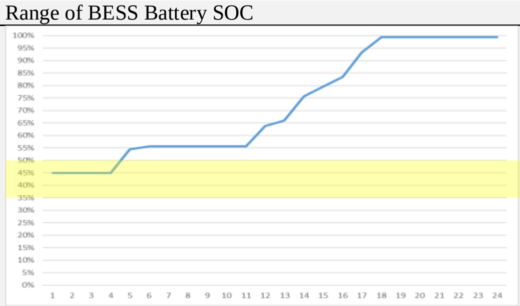
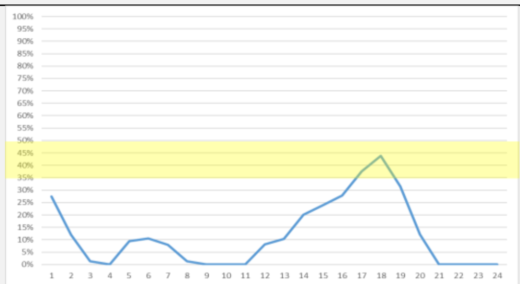
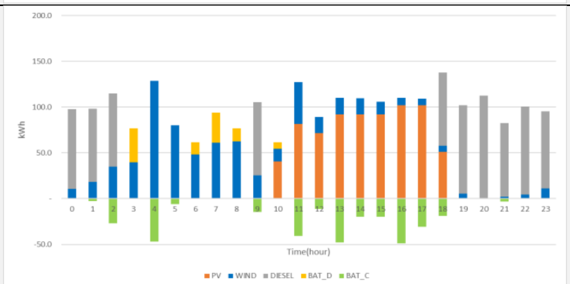
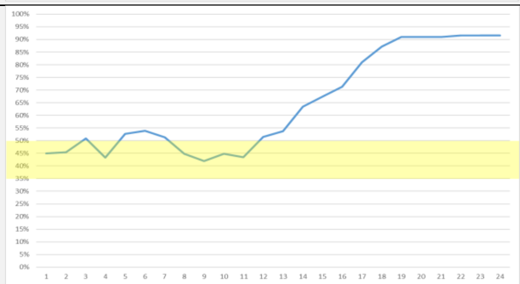
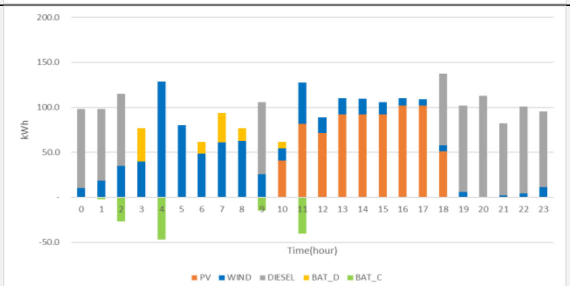
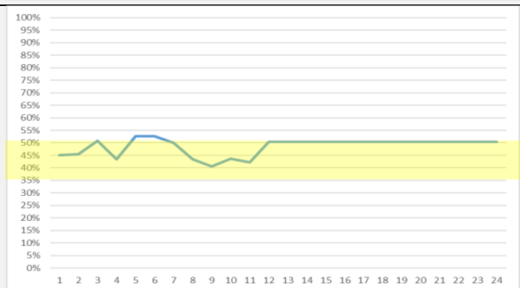
2-B-d		

Table 4 shows the simulation results for Scenario 3. There is a time zone where the renewable energy generation power exceeds the load power, and it is actually difficult to occur in Geocha island. In order to simulate various situations, actual data of Scenario 2 of October 5, 2016 was processed. The renewable energy generation power is suffciently, and it is possible to supply enough for the load with renewable energy. The operation method is the same as the scenario 1, 2.In 3-A-a, the diesel generator has priority, so the BESS is not discharged unless the power demand exceeds the total rated power of the diesel generator of 450 kW. In Scenario 3-B-c, the power remaining after driving the diesel generator according to the optimal power ratio is charged to the BESS in the section 0, 1, 9, 18, 21. Also, the load that subtracts the new regenerative power from the load is less than 40 kW, and the diesel generator is not driven by the algorithm, and BESS discharges instead in the section 3, 6~8, 10. And, in 3-B-d, the power is supplied to the load by driving the diesel generator, the remaining power is charged to the BESS, and the charged power is discharged when the load is less than 40 kW and the diesel generator output ratio becomes zero.

Table 4: Simulation Results: (Scenario 3) PV+WIND > LOAD

Scenario	Simulation Graph	Range of BESS Battery SOC
3-A-a		
3-A-b		
3-B-c		
3-B-d		

In this way, the diesel generator is operated only in the zone where the optimum efficiency is generated, and BESS is designed to operate only within the range where the optimum energy can be obtained, and the scenario is classified and simulated according to whether the algorithm is applied or not. As a result of simulations, in scenario 1-B-d, scenario 2-B-d, scenario 3-B-d, when the proposed algorithm is applied to the control of the diesel generator with optimal power ratio of 60 ~ 80% and operation of BESS SOC range of 35 ~ 50%, the optimum energy of BESS SOC can be obtained within the allowable range And it was confirmed that it was well controlled. Due to the nature of the development environment and the electricity demand of Geocha island, it was enough to operate only 2 out of 3 diesel generators operated.

5. Conclusion

In this paper, we analyze each MG component in a Geocha island where a standalone MG is constructed, and design a MG optimal operation algorithm that reflects the diesel generator and BESS battery characteristics. We also simulated scenarios based on algorithms. As a result, it is possible to minimize the fuel consumption of the diesel generator and optimize the energy of the BESS when the optimal operation algorithm is applied in all scenarios when the renewable energy generation exceeds, lacks, and equals to the power consumption. .

In this paper, we design optimal operation algorithm and verify the validity of the algorithm by simulation using real data. This is the first step in the development of the Semi-Wheel System. The Semi-Wheel System is a system that enables the validity of MG, which are difficult to implement in a short period of time due to modeling complexity, economic problem, and stability, through a system designed for optimal operation algorithm. The system is designed to control and measure variables, reflecting the characteristics of MG elements analyzed in various MG situations and various angles. We will also analyze the economic aspects of calculating and comparing the unit price of each scenario.

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